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DEVELOPMENT OF ELECTRICAL SWITCHGEAR FOR SPACE NUCLEAR ELECTRICAL SYSTEMS

QUARTERLY PROGRESS REPORT NO. 3
For Quarter Ending April 16, 1964

EDITED BY R. N. EDWARDS

prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NAS 3-2546 - PHASE I

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC
CINCINNATI 15, OHIO

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January 16, 1964 - April 16, 1964

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FOR
SPACE NUCLEAR ELECTRICAL SYSTEMS

CONTRACT NAS 3-2546 - PHASE I

Prepared for

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I. PROGRAM OBJECTIVES - PHASE I

Phase I is concerned with three types of switchgear for application in space nuclear electrical systems. These three devices have been typified for purposes of investigation and technology development as:

1. Main AC Circuit Breaker (1000 volts, 600 ampere, 2000 cycles, three phase)
2. Engine Contactor (10 KV, 10 amperes, DC)
3. Main DC Circuit Breaker (100 volts, 10,000 amperes, DC)

Objective environments for operation are:

1. Pressure - down to 10^{-15} Torr
2. Temperature - up to $1000^{\circ}F$
3. Radiation - up to 10^{15} fast neutrons/cm^2
   up to 10^9 rads-gamma

accumulated over a 20,000 hour life. Objective survival environment for shock, vibration, and acceleration is compatibility with the C-1B launch vehicle.

The approach selected in the proposal for device item 1 and 2 above is that of modifying General Electric Company's vacuum interrupter to make it suitable for these extended environments. The approach tentatively selected in the proposal for device item 3 above is that of a high pressure gas interrupter.

The specific objectives of Phase I are presently identified as follows:

1. Conduct combined literature search and application study to:
   a) confirm or modify approach selections
   b) obtain available data on probable temperature effects on interruption approaches
   c) obtain available data on probable radiation effects on interruption approaches

d) obtain available data pertaining to materials selection

e) identify missing data required to confirm and support feasibility of design approaches

f) establish device design requirements

2. Conduct material and other preliminary tests to fill in critical data gaps in materials behavior and interruption phenomena. The critical area presently identified is the testing of selected contact materials for welding properties in vacuum at the elevated temperature.

3. Conduct simplified full scale interruption capability tests for the AC circuit breakers at 2000 cycles and at room temperature and $1000^{\circ}F$.

4. Conduct simplified full scale interruption capability tests for the DC engine contactor at room temperature and $1000^{\circ}F$.

5. Develop conceptual designs for each of the three devices.

6. From the studies and tests confirm the general feasibility of the conceptual designs.

7. Prepare a schedule of work for detailed design, fabrication, and testing of the Main AC circuit breakers and DC engine contactor for Phase II.

II. GENERAL SUMMARY

A. A Program Review was held in the Advanced Technology Laboratories in Schenectady by Messrs. H. Schumacher and E.A. Koutnik, Contract Management Technical personnel from the NASA-Lewis Research Center on April 15 and 16. Others present were:

R.N. Edwards	SPPS - G.E.
H.E. Nicoll	SPPS - G.E.
J.P. Hanna	ATL - G.E.
L.J. Goldberg	ATL - G.E.
G.W. Kessler	ATL - G.E.
E.F. Travis	ATL - G.E.

B. The DC interruption test will be conducted in the Power Transmission Division - Philadelphia Laboratories Operation in conjunction with the AC test. This decision was based on the following:

1. Equipment was in place and in operation in the Switchgear Laboratory for 10KV-20 ampere interruption tests.
2. The necessary instrumentation is available.
3. Personnel trained in the performance of these DC interruption tests will be assigned to the task.

C. The materials testing equipment will be used for the DC interruption tests and with modification for the AC tests.

D. The contact materials to be tested for possible contact welding and for interruption characteristics will be limited to pure tungsten and molybdenum. The time schedule for the procurement of contact material made of tungsten impregnated with copper may dictate that tests of this material be deferred to Phase II. An effort is being made to obtain the material for limited tests during Phase I.

E. Preliminary tests have been conducted with the materials weld testing facility. Contact temperatures of 625 C and a vacuum of 10^{-6} Torr have been measured during the test runs.

F. Due to a change in the organization of the Advanced Technology Laboratories, E.F. Travis is now manager of this project replacing J.P. Hanna who has increased managerial responsibilities in the Electrical Engineering Laboratory. Mr. Hanna will still be actively supervising the project and will be available for consultation.

G. The revised PERT diagram included at the end of this report represents the present plans. The changes result from the following decisions:

   1. To delete both the AC and DC interruption tests of a commercial contactor with molybdenum contacts. The data on molybdenum will be obtained during materials tests in ATL and during the interruption test at the Switchgear Development Laboratory.
   2. To obtain sufficient contacts prior to the materials tests to provide contacts for the interruption test.
   3. To conduct the DC interruption tests in conjunction with the AC interruption test at the Switchgear Development Laboratory.
   4. To use the materials test equipment for the DC interruption test and for the AC interruption test with some modifications.

III. SWITCHGEAR REQUIREMENTS AND APPROACHES

A. Objective and Approach

Conduct a combined literature search and application study to -

1. Confirm or modify approach selections
2. Obtain available data on probable temperature effects on interruption approaches
3. Obtain available data on probable radiation effects on interruption approaches
4. Obtain available data pertaining to interruption materials selection
5. Identify missing data required to confirm and support feasibility of design approaches
6. Establish device design requirements

B. Current Quarter's Work

No significant work was performed during this quarter. Work will be resumed after the test program has furnished data in this area.

IV. DEVICE DESIGN

A. Objective and Approach

The objective of this part of the work is to produce conceptual designs of the three interrupters -

1. Main AC Circuit Breaker 1000 VAC 3∅ 600 A 2000 cps
2. Engine Contactor 10000 VDC 10 A
3. Main DC Circuit Breaker 100 VDC 10000 A

All of these will be designed to meet the environment of -

Temperature--1000°F

Life--20,000 hrs.

Vacuum--10^{-15} Torr

Radiation--10^{15} fast neutrons/cm^2

10^9 Rads-gamma

Shock, vibration, and acceleration--compatible with CIB Launch Vehicle

Work is to include consideration of both hermetically-sealed, gas filled conventional and open flexural actuator approaches.

B. Established Requirements

The following general requirements for the operating mechanism have been established:

1. For the a-c breaker:

   Electrode diameter: 1 inch approximately

   Gap: 1/8 to 1/2 inch (1/4 is being used in present sketches)

   Operating force: 25 to 50 lbs. (50 used presently)

   Free travel of impact opening: 1/16 to 1/8 inch (1/8 used presently)

Speed of travel at moment of contact: 20 to 80 inches/sec.

(40 used presently)

2. For the 10 kv, 10 ampere d-c contactor:

   Electrode diameter: 1/2 to 3/4 inch

   Gap: 1/4 inch approximately

   Operating force: 10 to 20 lbs.

   Free travel of impact opening: 1/16 to 1/8 inch

   Speed of travel: 20 to 80 inches/sec.

3. For the 100 v, 10,000 ampere d-c contactor:

   Electrode diameter: 4 to 5 inches (probably in a gas)

   Gap: 1/4 inch approximately

   Operating force: hundreds of lbs.

   Free travel of impact opening: 1/16 to 1/8 inch

   Speed of travel: 10 to 40 inches/sec.

   These may have to be tempered with experience.

C. <u>Current Quarter's Work</u>

No significant work was performed during this quarter. Work will be resumed after the test program has furnished more data.

V. TESTING

A. Objective and Approach

Provide test facilities, plans, and execution for the following:

1. Conduct material and other preliminary tests to fill in critical data gaps in materials behavior and interruption phenomena. The critical area presently identified is the testing of selected contact materials for welding properties in vacuum at the elevated temperature.
2. Conduct simplified full scale interruption capability tests for the AC circuit breakers at 60 and 2000 cycles and at room temperature and 1000°F (538°C) measuring the recovery characteristics and chopping level.
3. Conduct simplified full scale interruption capability tests for the DC engine contactor at room temperature and 1000°F measuring the recovery characteristics and chopping level.

The general approach in establishing the above test facilities is to locate existing equipment that would require the minimum of modification to perform the work required.

B. AC Interruption Equipment

The preliminary test at the G.E. Switchgear Development Laboratories, reported in the last quarterly report, showed that the equipment was satisfactory for the AC interruption tests. Therefore this facility will be used for the interruption testing on this project.

C. <u>DC Interruption Test</u>

The planning for the DC interruption test facility has been changed. Instead of modifying equipment in ATL, the test will be conducted in the Switchgear Development Laboratories on equipment now in operation. This equipment consists of a 250 microfarad capacitor bank that can be charged as high as 20 KV. At a 22 ampere discharge rate the current level will decrease 2 amperes in 12 milliseconds. The necessary timing equipment, instrumentation and trained personnel are available for the project DC interruption test.

D. <u>Contact Weld Test Equipment</u>

The weld test equipment consists of the following:

1. The alumina-Kovar gold-copper brazed vacuum envelope.
2. A fixed and movable electrode with contact tips that can be removed and replaced.
3. A bellows assembly to provide for the movement of the movable electrode.
4. A contact heater made of nickel strip.
5. An actuator for the movable contact.
6. Vacuum pumping equipment, interconnections and measurement equipment.
7. A sectional oven to provide the high ambient temperature of $450^{\circ}C$.

All of the above equipment with the exception of the temperature recording equipment, ion pump power supply and the mechanical fore pump is assembled on a small wheel-table for portability.

The alumina-kovar vacuum assembly is shown at (B) in Figure V-1. The top and bottom stainless steel flanges (A) and (C) are inert-gas welded to the kovar spinnings at each end of the gold-copper brazed assembly. The two flanges at the center of the assembly are the electrical connections to the heater to induce the desired contact temperature, 650°C.

Figure V-2 is the fixed electrode brazed to the top vacuum flange cover. A copper gasket is used between this cover and the top flange of the vacuum envelope. The end (C) of the stainless steel electrode (B) has a 5 degree taper. The contact material to be tested is brazed to a mild steel cap (D) which has a corresponding internal 5 degree taper. The contact material and cap are pressed on the electrode for a measured distance along the electrode axes to assure good electrical and thermal conductivity. The space between the shoulder on the electrode and the edge of the steel cap is gaged after finger pressing the cap on the electrode. This measured gap is then decreased by 0.015 inch by pressing the cap on the electrode. The greater thermal expansion of the stainless steel electrode with increased temperature further tends to increase the bond between the cap and electrode.

Figure V-3 shows the parts for the bellows assembly used to permit the movement of the bottom electrode and contact. All of the parts are inert gas welded except the electrode which is gold-copper brazed to part (D). The completed assembly ready for welding to the bottom cover flange is shown at (E).

The parts of the contact heater are shown in Figure V-4. The strip heater is made of 0.005 inch thick nickel A. The nickel strip is inert gas welded to the nickel contact bars (B) and (C) and one end of each of the contact bars is welded to one of the center flanges of the alumina-kovar vacuum envelope.

AC currents as high as 200 amperes can be used in the heater strip to provide the temperature differential between the oven ambient 450°C and the estimated contact temperature of 650°C. In a preliminary test a current of 125 amperes provided a contact temperature of 610°C.

The contact actuator, Figure V-7, includes a 60 cps solenoid (A) to furnish the closing force, a "caged" contact pressure spring (B) and a spring to counter-balance the atmospheric pressure on the bellows (C).

The "cage" of the contact pressure spring is adjustable to vary the contact pressure. Figure V-6 shows the pressure versus displacement, i.e., decrease in length. This spring is "caged" to give a contact pressure of 20 lbs at the instant of contact make and increases to 28 pounds during the remaining actuator travel of 1/8 inch.

Figure V-5 shows the variation in pressure with compression of the balance spring. The initial force to counter balance the atmospheric pressure is 15 pounds and the 1/4 inch movement of the contacts increases the force to 20 pounds. This additional 5 lbs. subtracts from the caged spring force resulting in a contact pressure of 23 lbs.

The original vacuum pumping equipment consisted of a sorption pump and an ion pump. During the debugging tests it was found that considerable time was required to "pump down" and in some cases the sorption pump would saturate. To reduce the "pump down" time a mechanical fore pump and liquid nitrogen vapor trap has been added. The section of the G.E. sorption pump connected to the liquid nitrogen trap is separated from the main pumping section and is filled with zeolite. This section is a vapor trap and further prevents the back vaporization of oil vapors from the mechanical pump.

The oven for providing the bake-out temperature of 450°C is made of sections of low density marrinite. The 5 KW oven heaters are attached to the two sides of the oven. The oven can be completely removed from the test set-up.

The complete system was pumped down and baked out at 300 C including the ion pump. The ion pump was then isolated from oven and the oven temperature was increased to 450°C, the top limit for the vacuum valve. The data recorded during the 450°C bake-out is tabulated in Figure V-8.

The temperature of the contact tips was raised above the oven temperature by the Nickel heater in the vacuum envelope. The maximum contact temperature reached was 625°C because a leak in the vacuum system developed and the test was terminated.

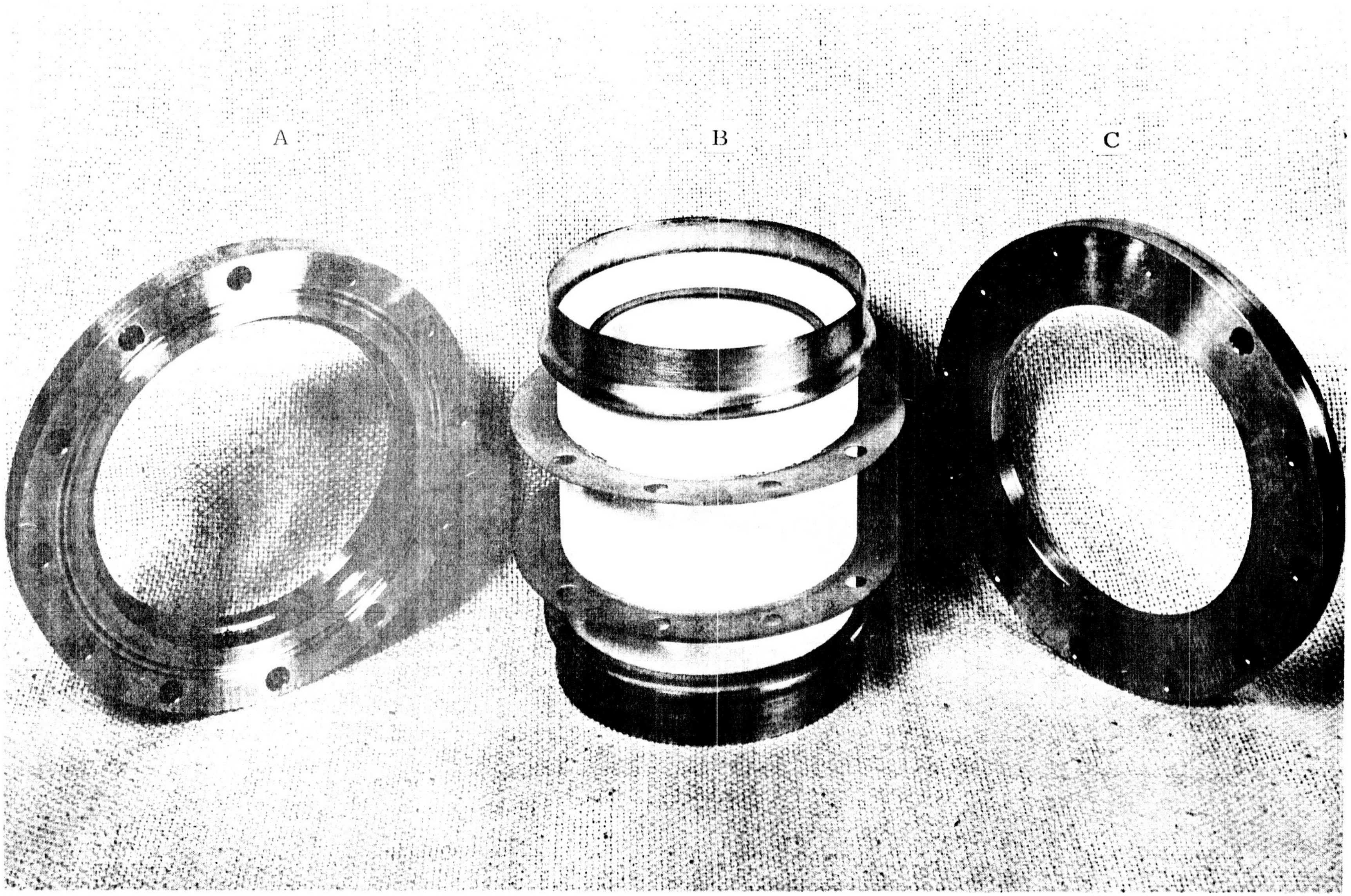


Figure V-1 VACUUM CHAMBER PARTS
A - Top Vacuum Flange
B - Alumina-Kovar Gold-Copper Brazed Envelope
C - Bottom Vacuum Flange

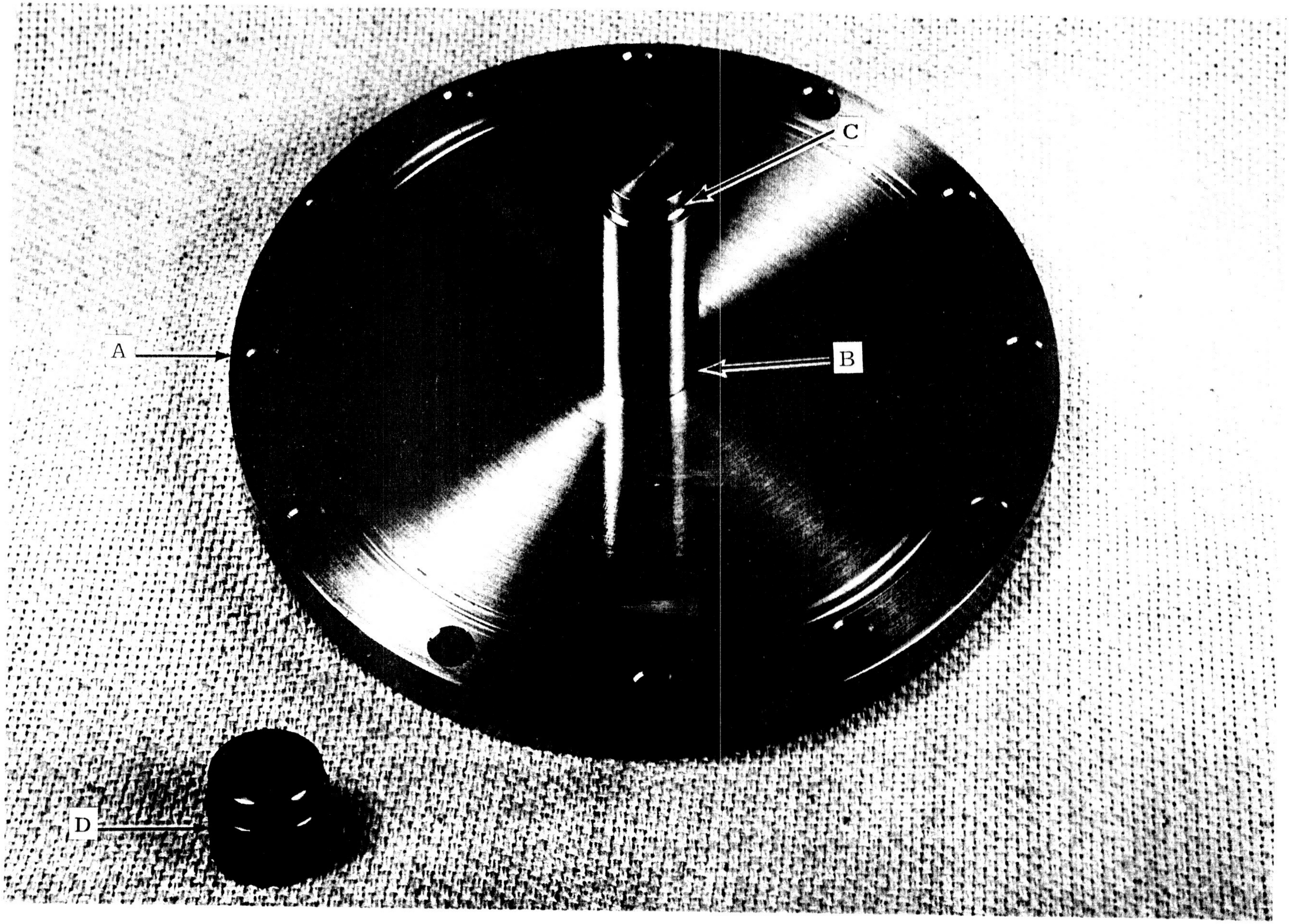


Figure V-2 TOP VACUUM FLANGE, ELECTRODE AND CONTACT ASSEMBLY
- A - Vacuum Flange
- B - Electrode
- C - Tapered Electrode End
- D - Contact Material Brazed to Mild Steel Internally tapered Electrode Cap

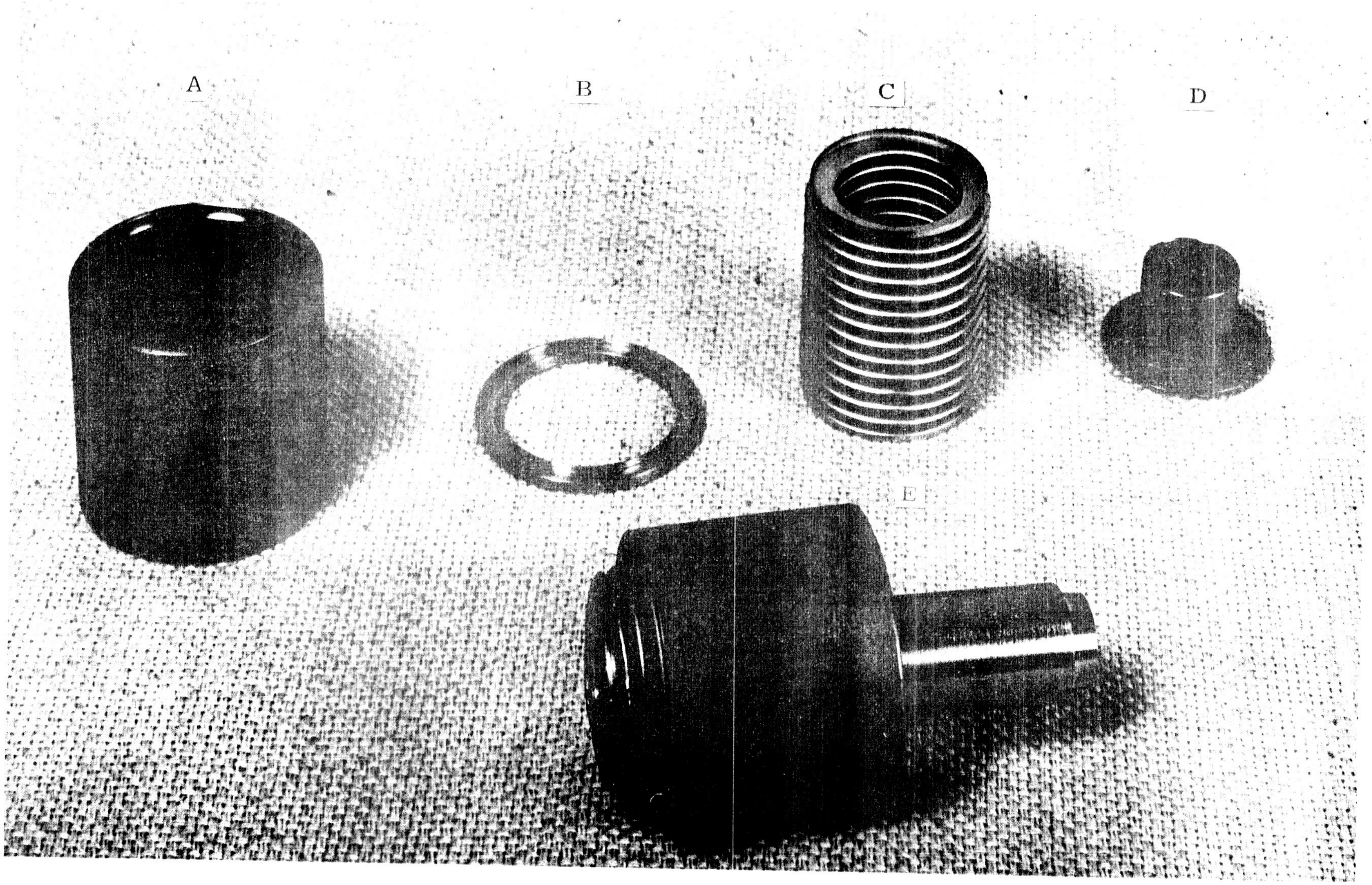


Figure V-3 MOVABLE ELECTRODE PARTS AND WELDED ASSEMBLY
A - Sleeve for Welding to Bottom Vacuum Flange
B - Ring Adapter Between Bellows and Part (A) above
C - Stainless Steel Bellows
D - Electrode Adapter to Bellows
E - Complete Welded Assembly

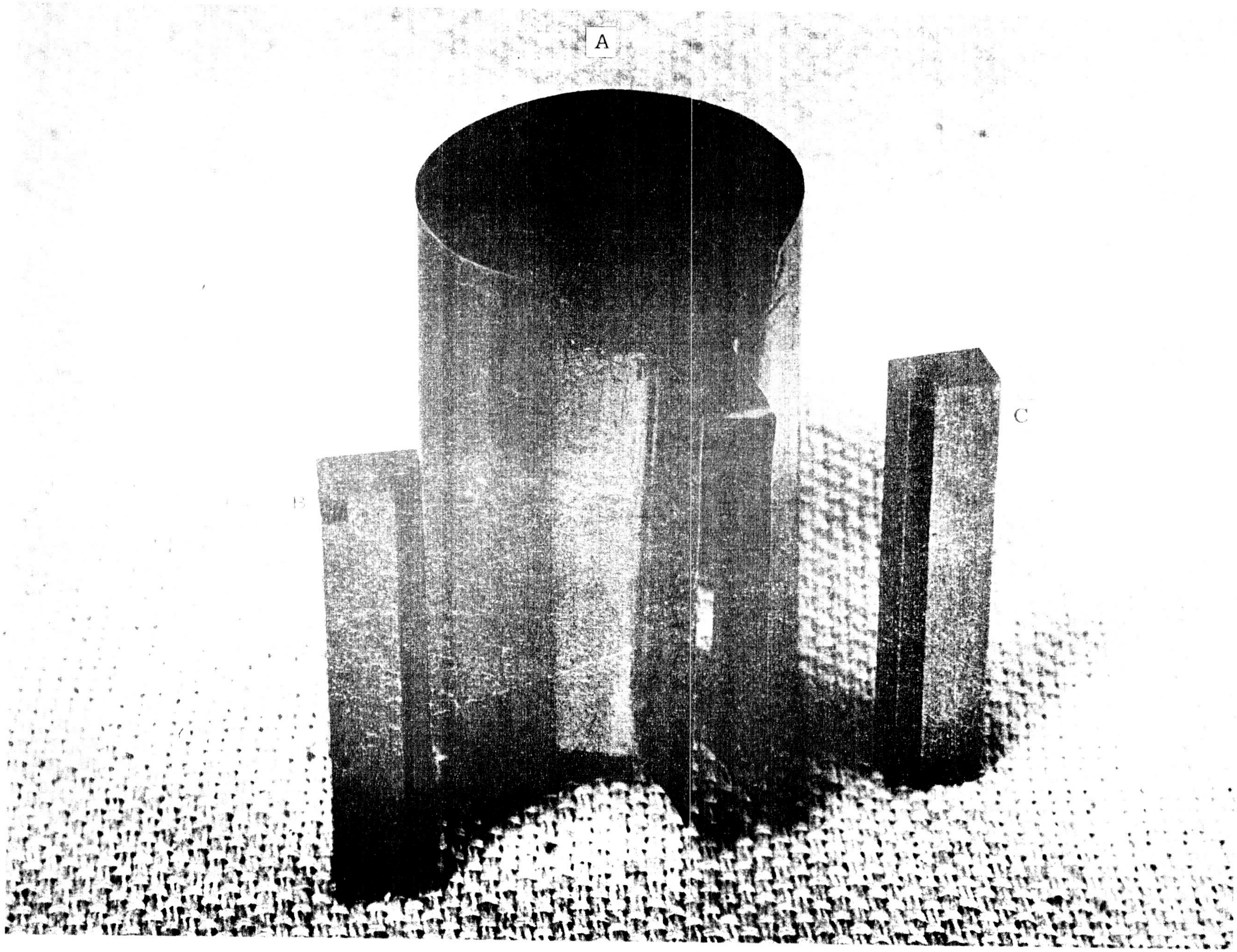
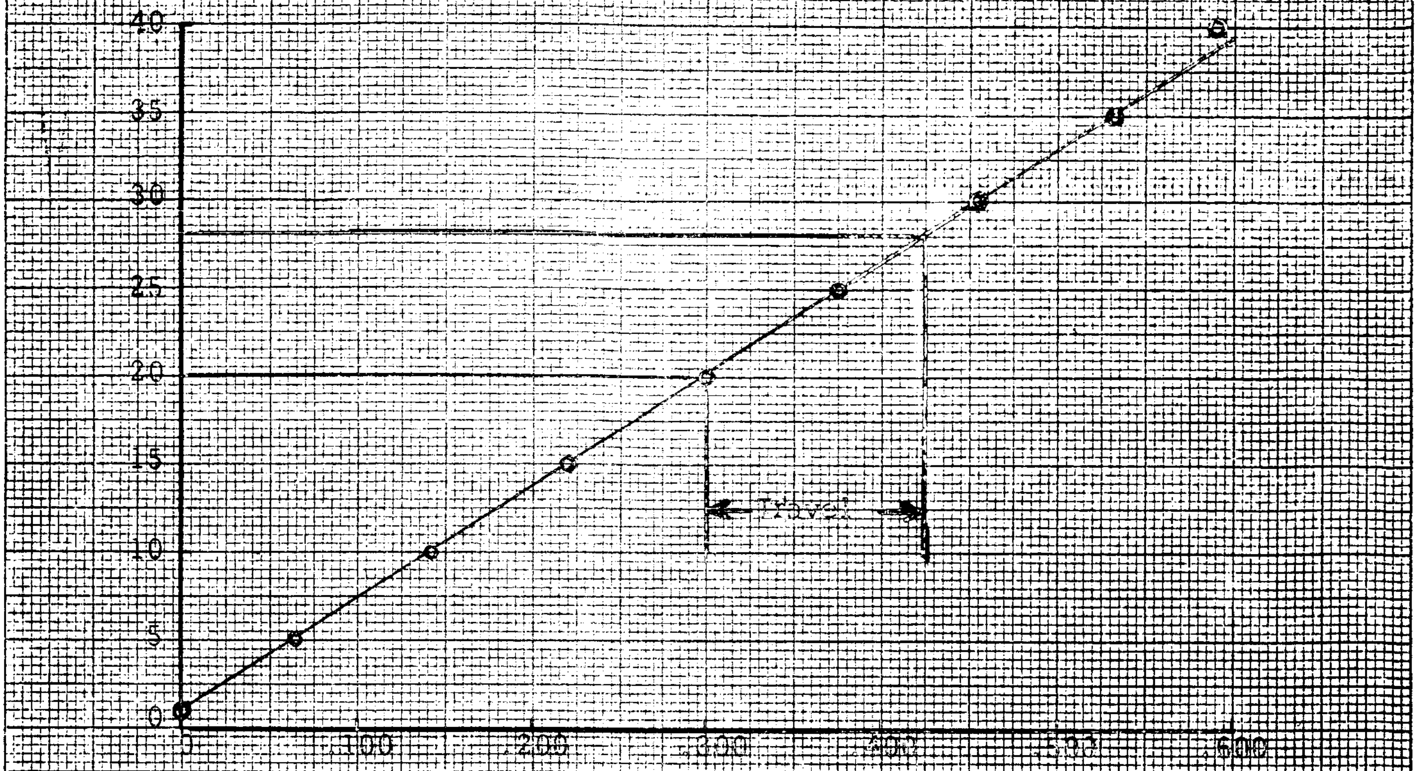
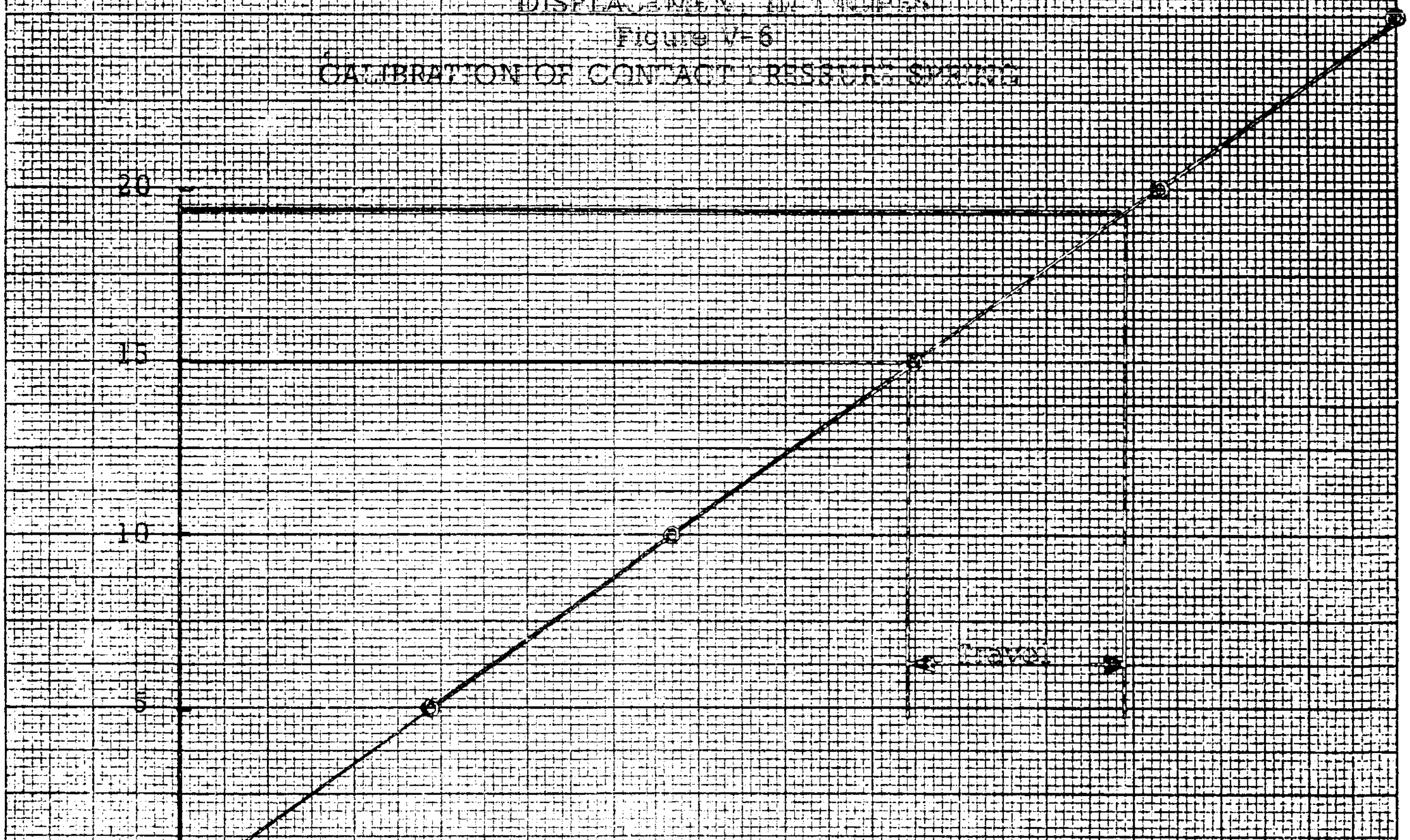


Figure V-4 CONTACT HEATER
A - Pure Nickel Strip Heater 0.005 Thick
B-C - Pure Nickel Contact Bars



DISPLACEMENT IN INCHES
Figure V-6
CALIBRATION OF CONTACT PRESSURE SPRING



DISPLACEMENT IN INCHES
Figure V-5
BALANCE SPRING CALIBRATION

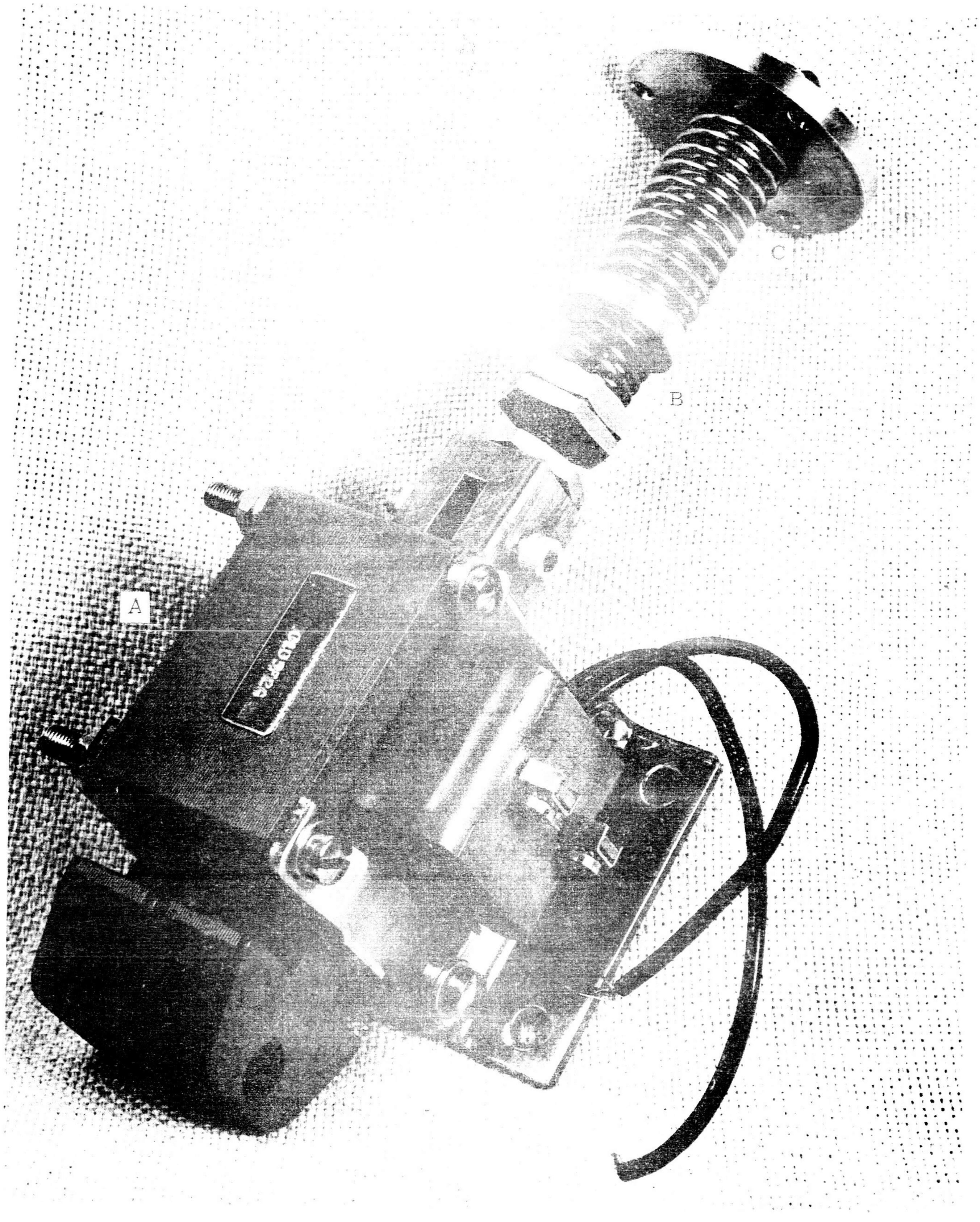


Figure V-7 CONTACT ACTUATOR
A - AC Solenoid
B - Caged Contact Pressure Spring
C - Counter Balance Spring

TUNGSTEN CONTACT MATERIALS TEST

Temperature °C

Time	Pressure (Torr)	Valve T1	Pump Magnet T2	Contacts Top T3	Contacts Bottom T4	Contact Heater Amperes
11:15	10^{-6}	Heat on				
11:30	10^{-5}	115°	40°	55°	55°	
11:40	$2x10^{-5}$	140°	40°	95°	95°	
11:45	$2x10^{-5}$	160°	40°	120°	120°	
11:50	10^{-4}	200°	40°	150°	150°	
11:55	$5x10^{-5}$	225°	45°	185°	185°	
12:05	$2x10^{-6}$	290°	55°	250°	250°	
12:16	$5x10^{-6}$	380°	70°	350°	350°	
12:22	10^{-5}	400°	70°	375°	372°	
12:30	10^{-5}	430°	75°	420°	415°	
12:32	$2x10^{-5}$	440°	75°	430°	427°	100
12:35	$2x10^{-5}$	435°		455°	455°	
12:42	$2x10^{-5}$	448°		505°	500°	
12:50	$2x10^{-5}$	448°		530°	535°	
12:55	$2x10^{-5}$	445°		540°	555°	50
1:05	$2x10^{-5}$	445°		542°	550°	100
1:10	$3x10^{-5}$	440°		555°	570°	150
1:18	$5x10^{-5}$	450°		588°	610°	125
1:25	Closed Valve. Ion Gage Dropped to $5x10^{-4}$ MM of Hg. All Heaters off.				625°	

4/15/64

Figure V-8

SWITCHGEAR DEVELOPMENT

Monthly Reports (drafts)
Aug. 22, Sept. 23, Nov. 22, Dec. 23, Feb. 24, Mar. 23, May 25, June 22

Quarterly Reports
Oct. 25, Jan. 24, Apr. 24, July 24

Final Report - August 31, 1964

Design Reviews -

Start Phase II Negotiations 6/22/64 - Complete by 7/28/64.

Revised 4-22-64